Memo: Sensor Network Architecture and Protocols

From: Telink Semiconductor

1 Overview

This document describes the tree-structured sensor network and the related protocol designs for use within supply chain management.

2 Function Requirements

2.1 Architecture Diagram

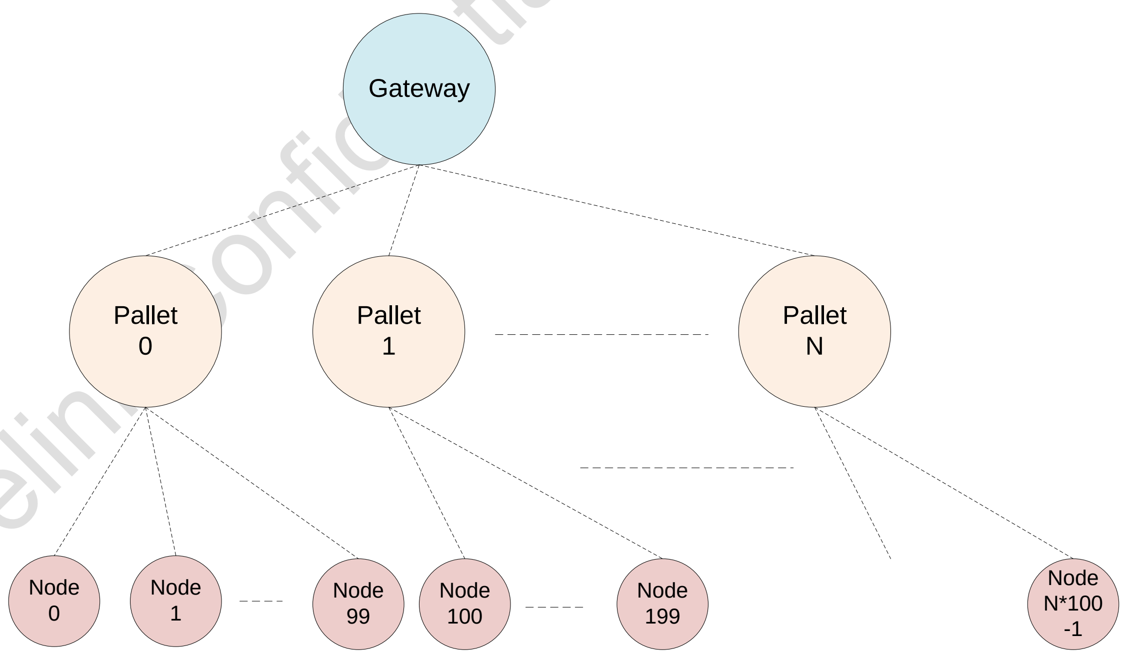

Figure 1 Sensor Nodes and relationship

In this sensor network, we consider three type of nodes:

- Node: the edge nodes that contains sensors and report information at very low duty cycle (1/15 minutes)

- Pallet: the coordinator that collects information from up to M (100) nodes and aggregate them

- Gateway: the central node that collects information from all Pallets and thus all nodes

All three types of nodes are required to be low power devices. Sensor nodes are normally supplied with 200mAh battery, while Pallet and Gateway may have 1800mAh or 3600mAh batteries. The required life time for all nodes is at least two months.

3 Network Timing and Power Consumption

3.1 General Network Timing

In order to achieve ultra low power, it is desired to have deterministic time slot based transmission opportunities so that the nodes can sleep as much as possible.

The timing relationship is shown in the following diagram.

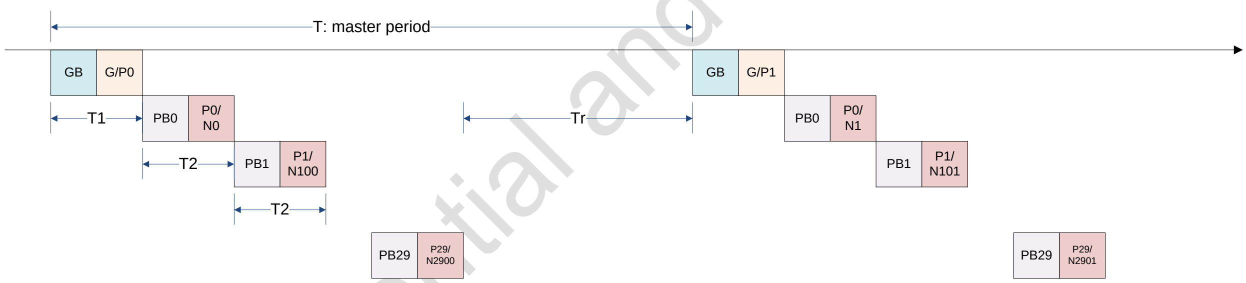

Figure 2 Network Timing

The network's timing is governed by the Gateway node and follows a master period of T (500ms). Within the time slots, the following transmissions are arranged:

- GB: gateway beacon, it contains information on overall master period count, which Pallet has opportunity in this period. The communication opportunity is assigned in a fixed round-robin pattern, so that any Pallet receiving the GB will be able to derive when its opportunity will come up.

- G/Pn: Gateway and Pallet #n bi-direction communication opportunity,

- PBn: Pallet #n beacon, it contains information on overall pallet period count, pallet ID, and which node is given the opportunity in this period

- Pn/Nm: Pallet #n to its child Node #m bi-direction communication opportunity

3.2 Network Timing Example

With the above set up, the following is an example set of parameters that can be used:

- T: master period, 500ms

- Tp: time duration for beacons, 1ms
- T1: GB timing + 1 communication opportunity with one of the Pallet, 1ms + 4ms = 5ms
- T2: PB timing + 1 communication opportunity with one of the child Nodes, 1ms + 4ms = 5ms
- Tr: T – T1 – N*T2, the remaining time budget that can be used to extend the protocol for other purposes

Given 30 Pallets and 100 child nodes for each pallet, the total timing is calculated as follows:

- RF channel activity within one master period: T1 + 30*T2 = 155ms
- Gateway active time within one master period: T1 = 5ms
- Pallet #n active time within one master period: T2 = 5ms
- Intervals for a Node to have one transmission opportunity to its Pallet: T*M = 500ms * 100 = 50s
- Within 15 minutes (900s), there are 1800 opportunities from Pallets to GW, this means the pallet to GW transmission need to have a certain level of aggregation (at least 2:1) to allow all information from 3000 nodes to be transmitted to the GW.

3.3 Power Consumption estimation

We use the following numbers in power estimation:

- RF SoC active current: 40mA (should be 30mA or less depending on power setting etc, but we try to give an upper bound here)
- RF SoC suspend current: 15uA, as can be seen from the calculation, there is no need to use the deepsleep state where the current is around 3uA with 32K OSC

The Gateway's power consumption:

Igw = (40mA * T1 + 0.015* (T – T1))/T = 0.415mA => 180days with 1800mAh battery

The Pallet's power consumption:

Ip = (40mA * T1 + 0.015* (T – T1))/T + 40mA * T1 / (N*T) = 0.416mA => 180 days with 1800mAh Battery

For the nodes current consumption, it depends on when how often the node needs to wake up to listen to its parent Pallet's PB for time synchronization. Let's assume it wakes up every K period other than the normal transmission opportunity and the overhead for Beacon listening and processing is the same as beacon length, then the power consumption becomes:

In = (40mA*T2 + 40mA * (M/K-1) * 2*Tp + 0.015 * (M*T – T2 – 2*(M/K-1)*Tp)) / (M*T) = 0.0174 + 0.1599/K

If K = 1, then the node wakes up every period for sync, then In = 0.177mA => 47 days for 200mAh

If K = 2, then the node wakes up every other period for sync, then In = 0.097mA => 86 days for 200mAh

3.4 Other design considerations

3.4.1 Resynchronization of orphaned nodes

Since all the Pallets broadcast Beacons with a lagged timing, it is very easy for a Node to re-sync, it only needs to receive one of the GB or PBs to get back to sync with the whole network.

3.4.2 Additional transmission opportunities

The node to pallet round-robin pattern can be extended by adding additional empty cycles, for example 128 as period for 100 nodes. This will leave 28 node-pallet opportunities for random access, which can be used by child nodes for extra emergency information or by other nodes that do not belong to this pallet for alternative path transmissions.

The same principle can be applied on the pallet-gateway round-robin pattern.

3.4.3 Use of extra time

In the current design, no transmission happens during Tr time where all nodes are sleeps. Additional transmissions can be scheduled here to later protocol extension.

3.4.4 Extending of the hierarchy

Since in the current timing allocation, only about 155ms activity time in 500ms is used. It is easy to extend the network hierarchy by one more level without causing major issue, but increase the number of supported nodes exponentially further more.

4 Network Setup

The network can be set up using a 3 step top-down and automatic approach.

In the first step, the gateway is turned on and forced into setup mode, it starts to broadcast GB with network steering information indicating the gateway is open to receive pallet attach request. During this period, gateway broadcasts steering-GB with interval T, but the remaining of the master period is open for Pallet to perform random attach request. The Pallet attach timing is shown in Figure 3. In addition to the steering-GB which follows the master period, additional secondary Steering-GB can also be added to allow Pallet to acquire the network faster.

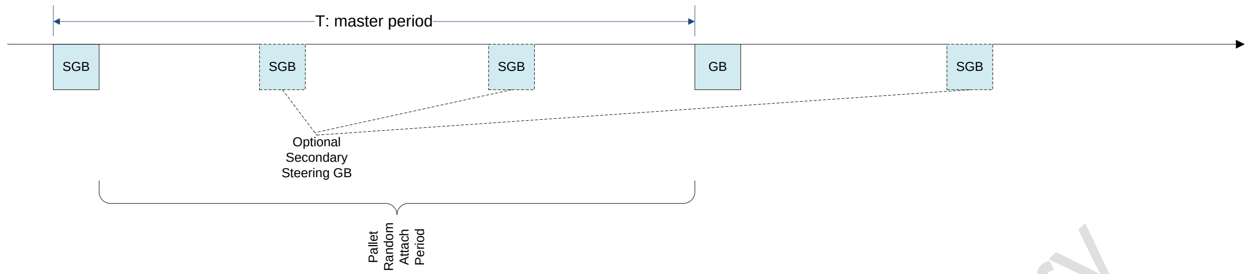

Figure 3 Pallet Attach Timing

In the second step, the pallets are turned on and forced into setup mode. All pallets searches for the steering-GB and send attach request to the gateway. The gateway replies to each pallet with their assigned address and also indicates in steering-GB which pallets have already attached successfully (e.g. using bit map).

In the third step, the gateway controls each pallet to forces them into setup mode subsequently. For example, Pallet #0 goes into setup mode first, allows all its children to attach. After completion, the gateway forces Pallet #1 into setup mode, and so, until all the pallets and nodes are allowed into the network.

For Pallet #0, the set up timing can be shown as follows. The Gateway broadcast on regular master period and the rest of the time is used by Pallet #0 for child attach.

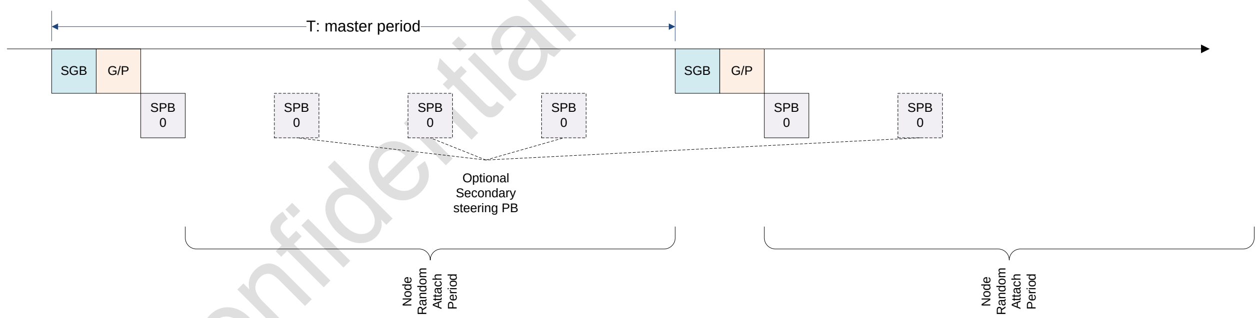

Figure 4 Node Attach

For subsequent Pallets, the set up timing can have two alternatives:

- Alternative 1: This follows the same timing as shown for Pallet #0, the entire master period can be reserved for Pallet n setup. However, Pallet 0 ~ n-1 and the nodes attached to them needs to be notified to stay quiet for a certain period, before they can come back and search for the parent timing for re-synchronization. In this case, the network boot time needs to be set up properly to allow all Pallets and nodes to be commissioned, otherwise, the commissioned nodes may come back earlier before all nodes can be commissioned and thus causing problem.

- Alternative 2: After each Pallet is provided, it starts to transmit Beacon on regular beacon timing and only the remaining master periods are used for additional commissioning. This timing is shown in Figure 5. All commissioned Pallets and nodes starts to run on normal timing, the rest of the time slots are used for remaining Pallet setup. This approach allows nodes to be commissioned as long as they need. However, the setup time for Pallet with higher addresses may be much longer than that for Pallets with lower addresses.

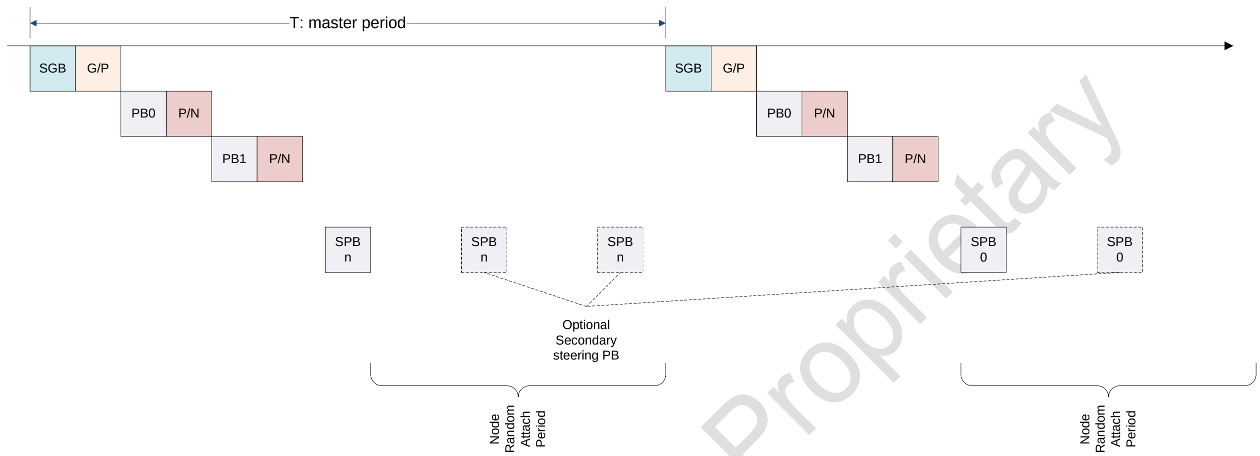

Figure 5 Nodes attach to Pallet #n

5 Change Log

2016/8/8, initial release